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PROJECT DIAMOND ORE; PHASE IIA: EFFECTIVENESS OF CRATERS AS BARRIERS TO MOBILITY

Claude A. Blackmon, et al

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

May 1973

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by

C. A. Blackmon, C. E. Green

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Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station
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Vicksburg, Mississippi

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Project DIAMOND ORE Phase IIA consisted of the detonation of three 10-ton charges of aluminized ammonium nitrate slurry at different depths of burst (DOB) and stemming conditions near Fort Peck, Montana, in October 1972. The purpose of the investigation described herein was to determine the effectiveness of the three craters as barriers to the performance of an M48A2 tank. The unstemmed charge at optimum DOB that formed crater IIA-1 created a marginal condition of "go-no go" for the tank. The stemmed charge at optimum DOB that formed crater IIA-2 and the stemmed charge at approximately one-half optimum DOB that formed crater IIA-3 created definite barriers to the tank. There were indications that a more effective barrier for the tank was produced by the stemmed charge at approximately one-half optimum DOB than by the stemmed charge at optimum DOB. The time required for a D-9 tractor to make crater IIA-3 passable for the M48A2 tank was 1 hour.

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ABSTRACT

Project DIAMOND ORE Phase IIA consisted of the detonation of three 10-ton charges of aluminized ammonium nitrate slurry at different depths of burst (DOB) and stemming conditions near Fort Peck, Montana, in October 1972. The purpose of the investigation described herein was to determine the effectiveness of the three craters as barriers to the performance of an M48A2 tank.

The unstemmed charge at optimum DOB that formed crater IIA-1 created a marginal condition of "go-no go" for the tank. The stemmed charge at optimum DOB that formed crater IIA-2 and the stemmed charge at approximately one-half optimum DOB that formed crater IIA-3 created definite barriers to the tank. There were indications that a more effective barrier for the tank was produced by the stemmed charge at approximately one-half optimum DOB than by the stemmed charge at optimum DOB. The time required for a D-9 tractor to make crater IIA-3 passable for the M48A2 tank was 1 hour.

PREFACE

The investigation reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) as a part of Project 4A062117A880, "Nuclear Construction and Engineering," Task 04, "Optimized Nuclear Barrier Systems," Work Unit 001, "Evaluate Crater Obstacle Potential," under the sponsorship of the Office, Chief of Engineers.

The field work was conducted during the period 12-14 November 1972 under the direction of MAJ John O'Conner, Explosives Excavation Research Laboratory (EERL), WES, and by Messrs. C. A. Blackmon and R. G. Temple of the Mobility Research and Methodology Branch, Mobility Systems Division (MSD), Mobility and Environmental Systems Laboratory (MESL); and John W. Meyer of the Weapons Effects Laboratory. Other personnel from EERL in the field were Messrs. John Dishon and Gerry Lakeman. All phases of the study were under the direct supervision of Messrs. E. S. Rush, Chief, Mobility Investigations Branch (MIB), and A. A. Rula, Chief, MSD, and under the general guidance of Mr. W. G. Shockley, Chief, MESL. This report was prepared by Messrs. Blackmon and C. E. Green, MIB.

Acknowledgment is made to Mr. John Kuncheff, Chief of Construction, Fort Peck, Montana, who furnished logistical support, and to C Troop, 1/163 Armored Cavalry Regiment, Montana National Guard, which furnished the test vehicle and personnel to drive and assist in transporting the vehicle.

Director of the WES during the conduct of this study and the preparation of the report was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

FIGURES

CONVERSION FACTORS, BRITISH TO METRIC AND METRIC TO BRITISH UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	British to Metric	
inches	25.4	millimeters
feet	0.3048	meters
pounds	0.4536	kilograms
tons (short)	907.185	kilograms
square inches	645.16	square millimeters
square feet	0.0929	square meters
pounds per square inch	6.8948	kilopascals
feet per minute	0.3048	meters per minute
feet per kilotons	0.000336	meters per metric ton
cubic yards	0.764555	cubic meters
	Metric to British	
meters	3.2808	feet

CHAPTER 1

INTRODUCTION

The possibility of creating significant tactical barriers to vehicular mobility with large surface or near-surface explosions, as with the atomic demolition munition (ADM), has been the subject of speculation for several years. A number of questions need to be answered, but the most important one concerns the actual mobility restriction that can be achieved for a combat vehicle attempting to traverse a full-scale (or approximately full-scale) crater and associated ejecta field, and the type and amount of man-machine hours required to make the crater passable. Once a sufficient number of tests have been conducted with tactical vehicles in a variety of sizes and shapes of craters created in various geologic media, pertinent relations can be established between crater parameters and vehicle characteristics for estimating tactical vehicle performance on a go-no go basis and engineering effort requirements. The results can then be incorporated in field manuals for use by troops in a theater of operations.

1.1 PREVIOUS INVESTIGATIONS

Prior to this study, two programs had been conducted with military vehicles to determine their ability to traverse craters typical of those that could be produced with an ADM. In 1964[1] tests were conducted in conjunction with Project TANK TRAP with an M60 tank, an M113 armored personnel carrier, and an articulated, two-unit, general-purpose tracked vehicle called the Polecat. Trafficability-type tests were run in the SCOOTER crater, the Jangle U crater, and the Pre-Schooner Bravo crater. The results of these tests indicated that: (a) craters formed in dry soil by the detonation of explosives at the surface or at very shallow

depths of burst (down to approximately 20 $ft/kt^{1/3.4}$)* do not present mobility problems to tracked vehicles; (b) craters formed at or near optimum depth of burst (160 $ft/kt^{1/3.4}$) in dry soil are a mobility obstacle to tracked tactical vehicles; and (c) craters formed in hard rock, such as basalt, cannot be negotiated by tracked tactical vehicles without major modification of the crater and/or assistance by heavy-duty equipment, either mobile or fixed.

Another military vehicle test program was conducted in July 1970 during EVENT DIAL PACK.[2] A crater was formed in a lean clay by the detonation of a spherical 500-ton TNT above-surface tangent blast. An M37, 3/4-ton cargo truck and an M113 armored personnel carrier were used as test vehicles. Four vehicle performance parameters (go-no go, drawbar pull, motion resistance, and speed) were evaluated in this study. The crater was divided into four units for mobility purposes--the outer lip, the inner lip, the crater wall, and the crater floor--established on the basis of difference in type of material, strength, slope, and size and spacing of soil clods. On the basis of go-no go performance, it was concluded that the M37 truck could not negotiate the crater floor or the crater wall; whereas the M113 armored personnel carrier could negotiate all terrain units except the crater floor. It was estimated that 3 to 4 hours of bulldozer (D7 or D8) time would be required to make the crater passable for 100 passages of conventional military vehicles.

1.2 PURPOSE AND SCOPE

The general purpose of this investigation was to determine the effectiveness of three craters and their associated ejecta fields in constituting a physical barrier to the movement of tactical military vehicles; and for the craters that were impassable, to determine the amount of engineering effort (bulldozer) required to construct a passable path for the vehicles under consideration.

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* A table of factors for converting British to metric and metric to British units of measurement is presented on page 7.

Although tests were planned for an M48A2 tank and an armored personnel carrier, only the tank was in suitable operating condition. Hence, the tests were limited to a single vehicle.

CHAPTER 2

TEST PROGRAM

2.1 LOCATION AND DESCRIPTION OF TEST AREA

The test area was located on the Fort Peck Reservoir reservation south of Glasgow, Montana (see vicinity map, Figure 2.1). Three craters were formed in October 1972 by the detonation of 10-ton charges of aluminized ammonium nitrate slurry (equivalent to 16 tons of TNT). The specific locations of the three craters are shown in Figure 2.2. The craters are identified as IIA-1, IIA-2, and IIA-3. Crater IIA-1 (Figure 2.3) was formed by an unstemmed charge placed at optimum depth of burst (DOB = 41.1 feet), crater IIA-2 (Figure 2.4) by a fully stemmed charge placed at optimum DOB, and crater IIA-3 (Figure 2.5) by a fully stemmed charge at a 6-m (19.68 ft) DOB.

The material in the area was identified as clay shale of the Bearpaw formation,[3] which is marine in origin and consists of dark brownish to blue-gray shales containing scattered layers or lenses of bentonite up to 2 feet thick. Along the Missouri River, the formation is over 1100 feet thick and overlies Judith River sandstone. Near the top of the formation, the shale is more silty or sandy than near the base. The entire reach of the Bearpaw formation is characterized by slump topography. The sediments are easily eroded and form a rounded "bad-land" type of topography in which local relief is generally less than 100 feet. Surface runoff is good; however, after heavy rains the surface may be muddy for several days.

The term "clay shale" has been widely adopted, but has not achieved a precise and universal meaning; however, in engineering circles the term generally refers to materials of sedimentary origin composed largely of silt- and clay-sized particles, which may or may not be slightly cemented by foreign agents, such as iron oxide, calcite, or silica, and which have been subjected to overburden loads sufficient to cause a high degree of overconsolidation. For

instance, the estimated thickness of the glacial ice cover of the Bearpaw formation is 1200 ft; this would have yielded a load of approximately 40 ton/ft^2. The material is composed principally of clay minerals and pieces of intact material tending to slake when exposed to cyclic wetting and drying. Materials cemented to the extent that they do not slake when exposed to cyclic wetting and drying are termed siltstone or claystone, depending on the particle gradation (Figure 2.6).

2.2 TEST VEHICLE

The test vehicle was an M48A2 tank (Figure 2.7) furnished by the Montana National Guard Unit at Glasgow, Montana. Engineering data pertinent to this study are given in the following tabulation:

Gross vehicle weight, pounds	98,000
Track	
Contact length, inches	164
Width, inches	28
Shoe, inches	7
Bogies on ground, per side	6
Ground clearance, inches	19
Engine type	Gasoline
Brake horsepower	810
Transmission	Automatic

2.3 TESTS CONDUCTED

Self-propelled go-no go mobility tests were conducted in the three craters with the M48A2 tank. The tank was positioned near the rim of the crater and a D-9 tractor (with blade and winch) stationed about 20 feet to the rear was attached to the tank with the winch cable. The tank proceeded cautiously over the rim with the D-9 tractor following until the tractor neared the rim. At this point the tank stopped and the safety cable was disconnected. The tank then proceeded down the crater wall and attempted to exit up the opposite wall. If the tank could not exit the crater unassisted, it was retrieved by using the winch and cable on the D-9 tractor. Then the tractor was used to do the minimum amount of work required to make the crater passable for the tank. The time required for this work was recorded as the amount of engineering effort required to make the crater a "go" situation for the M48A2 tank.

2.4 TERRAIN DATA OBTAINED

2.4.1 Surface Configuration. To characterize the craters, profiles for each crater elevation were measured along and perpendicular to crater radii by standard surveying techniques. The approximate locations of these profiles are shown by the dashed lines in figures 2.3, 2.4, and 2.5.

2.4.2 Soil Strength. The U. S. Army Engineer Waterways Experiment Station (WES) standard cone penetrometer was used to obtain an index of the shear strength of the soil at prescribed depths. This instrument (figure 2.8) consists of a 30-degree cone with a 1/2-inch^2 base mounted on the end of a 3/8-inch shaft, and a proving ring and handle mounted on the other. The force required to vertically penetrate the soil is indicated on a dial inside the proving ring. This force, in pounds per square inch, is read visually while the cone is forced into the ground by hand at the rate of 6 ft/min. This force is considered to be the index of soil strength and is generally considered to be dimensionless.

Soil strength was measured in terms of average cone index for each test course in each crater. Measurements were made at the surface and in 3-inch vertical increments to a depth of 18 inches, or until the capacity of the instrument was reached, whichever occurred first.

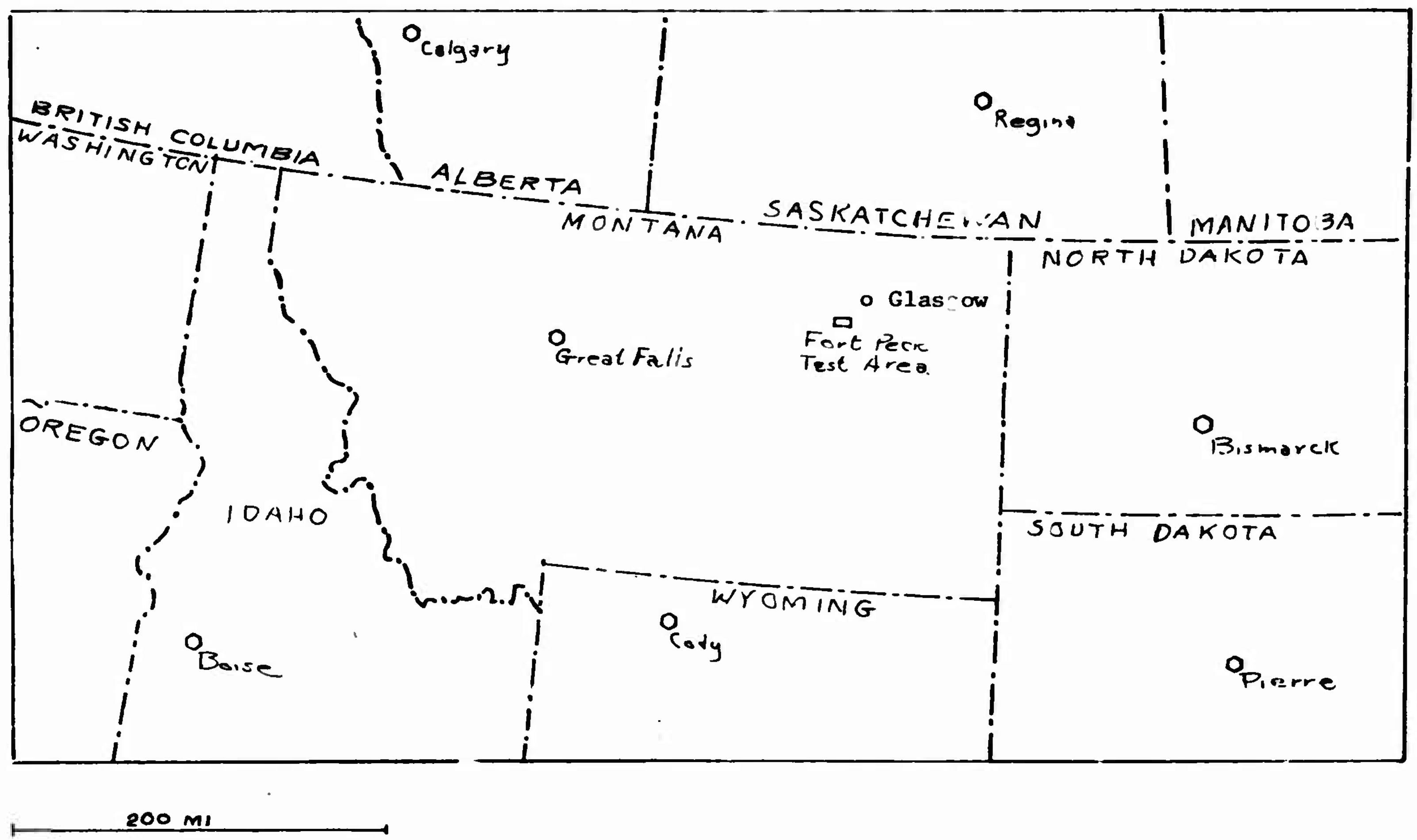


Figure 2.1 Vicinity map.

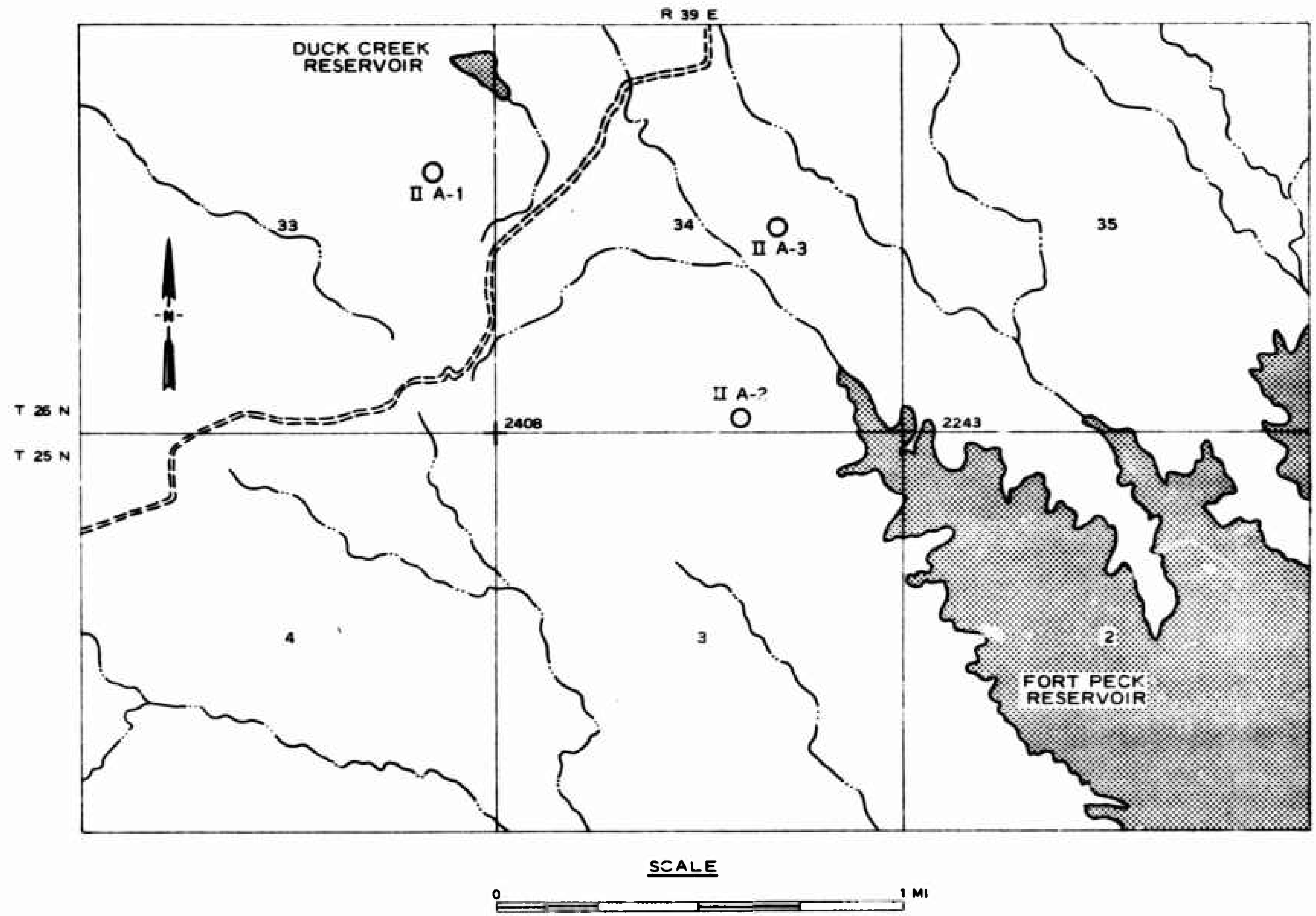


Figure 2.2 Location map.

Figure 2.3 Aerial photograph of crater IIA-1; dashed lines indicate location of elevation profiles shown in Figure 3.2.

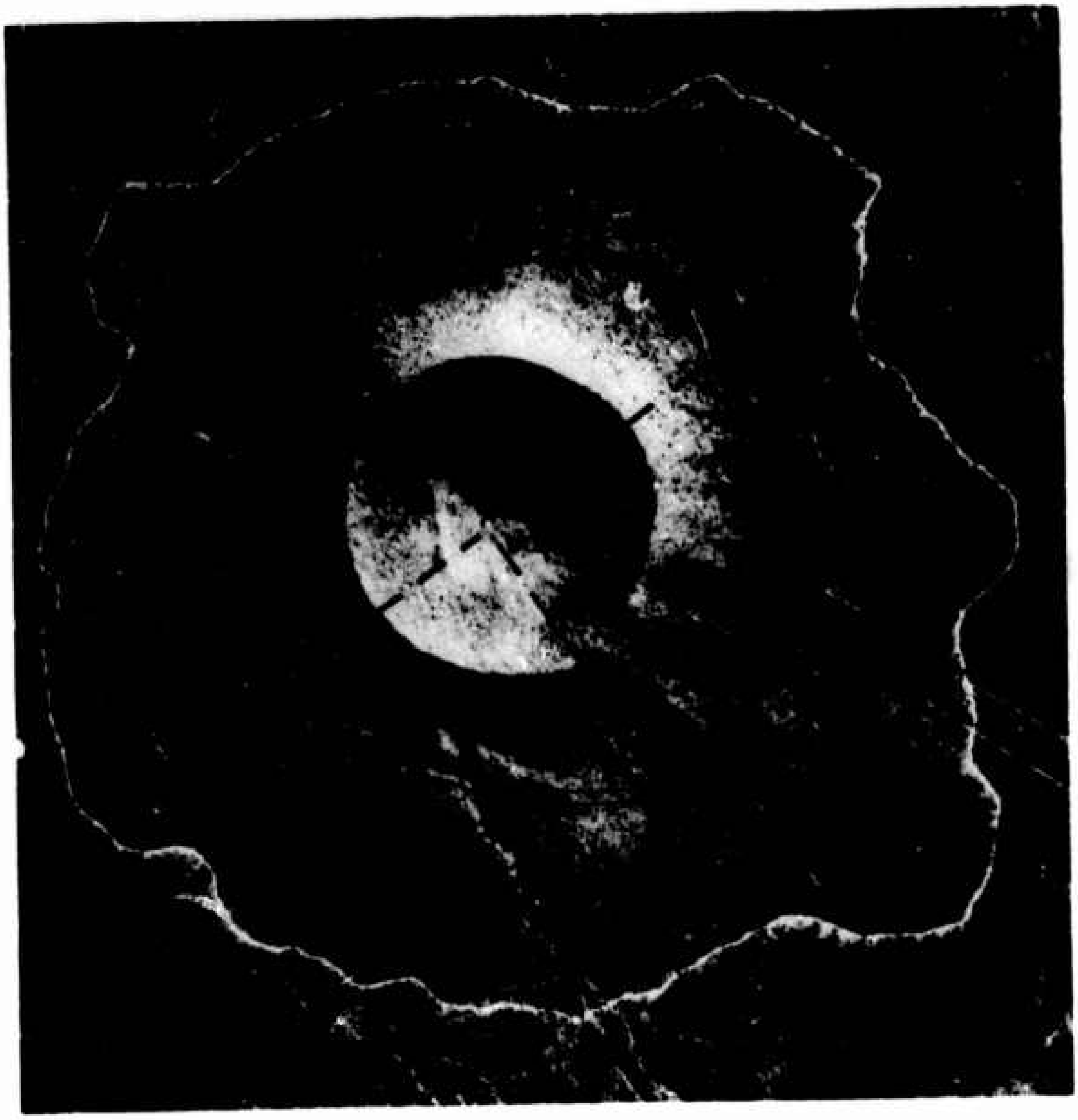


Figure 2.4 Aerial photograph of crater IIA-2; dashed lines indicate location of elevation profiles shown in Figure 3.3.

Figure 2.5 Aerial photograph of crater IIA-3; dashed lines indicate location of elevation profiles shown in Figure 3.4.

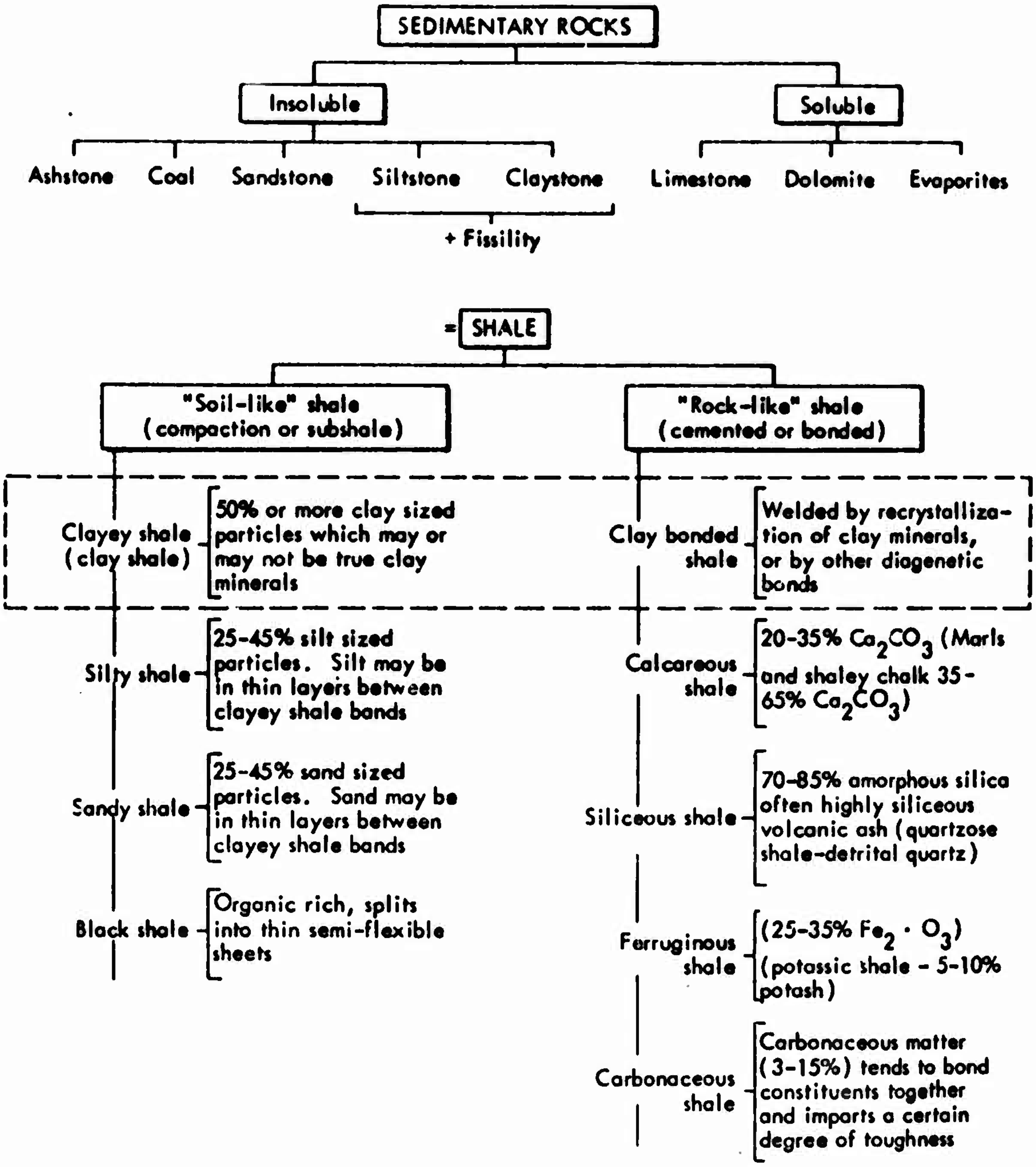


Figure 2.6 A geologic classification of shales.

Fig. 2.7 M48A2 tank.

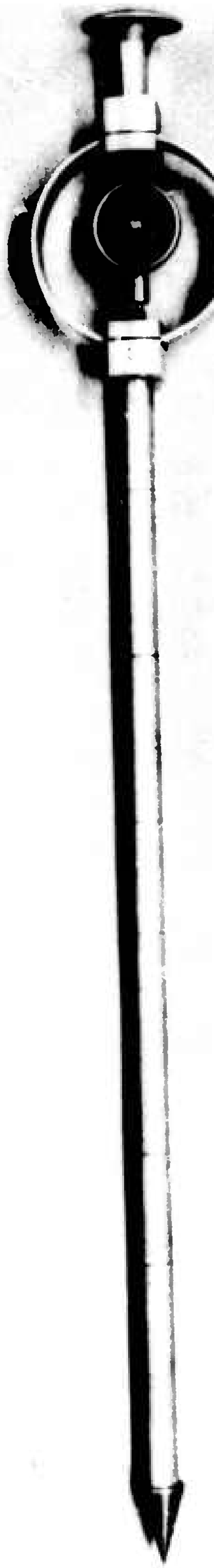


Figure 2.8 Cone penetrometer.

CHAPTER 3

TEST RESULTS AND ANALYSES

The results of this investigation are discussed in two sections: Description of the Craters for Mobility Purposes, and Vehicle Performance on a Go-No Go Basis.

3.1 DESCRIPTION OF THE CRATERS FOR MOBILITY PURPOSES

3.1.1 Terrain Units. The DIAMOND ORE Phase IIA craters were of approximately similar size, but with some differences in configuration. For mobility purposes the craters, with their associated ejecta, and the natural terrain were divided into four terrain units following the scheme presented in Reference 2. These four terrain units (Figure 3.1) were:

- Terrain Unit 1. (Original surface) The area past the limit of the ejecta sheet.
- Terrain Unit 2. (Outer lip) The area of continuous shallow ejecta extending from the natural terrain to the foot of the lip slope.
- Terrain Unit 3. (Inner lip) The area from the foot of the lip slope to the lip crest.
- Terrain Unit 4. (Crater wall) The sloping sides of the crater extending from the lip crest to ground zero (GZ).

Significantly, the terrain unit identified as the crater floor in the EVENT DIAL PACK crater did not exist in these three craters. This is as would be expected of craters formed by charges at optimum DOB and 6-meter DOB. The EVENT DIAL PACK crater was formed by a charge tangent to the surface and it did, typically, have a crater floor.

3.1.2 Terrain Data. Elevation profiles of craters IIA-1, IIA-2, and IIA-3 are shown in Figures 3.2, 3.3, and 3.4, respectively. Also shown in each of these figures is the elevation profile (dashed lines) of the natural ground surface before the crater was formed. Typical

microprofiles of the crater walls (Terrain Unit 4) and the inner lips (Terrain Unit 3) are shown in Figures 3.5, 3.6, and 3.7. Physical measurements of the craters are given in Table 3.1. In Figures 3.2, 3.3, and 3.4, and in Table 3.1, the differences between craters IIA-1 (unstemmed charge) and IIA-2 (stemmed charge)--both at optimum DOB--appear rather subtle. Crater IIA-1 was very slightly larger in diameter (162 versus 160 feet) and deeper (25 versus 23 feet from original ground surface) than crater IIA-2. The lip crest of the latter was higher above the original ground surface (14 versus 12 feet); thus the total relief, i.e. the vertical distance from lip crest to bottom of crater, was equal for these two craters, 25 + 12 = 23 + 14.

The effect of DOB was aptly demonstrated in crater IIA-3. Figures 3.2, 3.3, and 3.4 and Table 3.1 show that (a) the diameter of crater IIA-3 was significantly smaller than that of either of the other two craters, (b) the crater depth below the original ground surface was greater, and (c) the lip crest height above the original ground surface was less. However, the total relief, again expressed as the vertical distance between the lip crest and the bottom of the crater, was actually 1 foot greater in crater IIA-3 than in craters IIA-1 and IIA-2.

It should be pointed out that the slope of the crater wall given in Table 3.1 represents the maximum effective slope, i.e. the maximum slope of a segment at least equal to a vehicle length. Also, note in Figure 3.3 that the profile for crater IIA-2 shows a very short segment of very steep slope near the rim of the crater.

3.1.3 Soil Strength Data. The cone index (strength) data are summarized in Table 3.2 and are shown graphically in Figure 3.8. The cone index profiles for all three craters in Figure 3.8 show that the soil strength was greatest in Terrain Unit 1, and progressively decreased in Terrain Units 2, 3, and 4; and that the soil strength generally increased with an increase in depth. The cone index profiles appear to show a reasonable approximation of the ejecta depth. Note that slopes of the cone index profiles for the outer lip below 6 inches, the inner lip below 9 inches, and the crater wall

of crater IIA-1 below 15 inches are quite similar to the slopes of the cone index profiles of the original surface. This would suggest an average ejecta depth of 6 to 9 inches for the outer lips of the three craters, 9 to 12 inches for the inner lips of the three craters, and 15 to 18 inches for the crater wall in crater IIA-1. The cone index profiles for crater walls of crater IIA-2 and IIA-3 appear to indicate that the ejecta depth was greater than 18 inches. Note also that the cone index for the crater wall of crater IIA-3 was very nearly uniform below 9 inches, which further suggests a considerable amount of loose (small fragments) fallback.

3.1.4 Analysis. The differences in cone index and in ejecta depth on the crater walls of three craters, all of which had the same maximum slope, may be explained in part by considering the manner in which the craters were formed. Crater IIA-1 (unstemmed charge at optimum DOB) was the largest in diameter with the least ejecta on the walls; crater IIA-2 (stemmed charge at optimum DOB) was nearly as large as crater IIA-1, but had more ejecta on the walls; crater IIA-3 (unstemmed charge at 6-m DOB) was the smallest in diameter and had more ejecta on the walls than crater IIA-1. The greater strength as shown by the cone index of the crater wall of crater IIA-2 as compared with crater IIA-3 resulted from larger fragments of ejecta falling back into the crater. These results are as would be expected from the three charge configurations.

The maximum slope on the crater walls represented the natural angle of repose of the fallback material and was therefore the same for all three craters. It should be remembered that the elevation profiles shown in Figures 3.2, 3.3, and 3.4 represent the apparent craters; it is obvious from the foregoing discussion that greater differences would have been found in the true craters had they been excavated.

3.2 VEHICLE PERFORMANCE ON A GO-NO GO BASIS

3.2.1 Crater IIA-1. The M48A2 tank entered the crater without difficulty (although the safety cable snapped) and climbed about

four-fifths the way up the crater wall. The driver then backed down the crater wall and halfway up the opposite side in order to have a running start. This procedure was repeated and the tank was able to climb out on the twelfth attempt. The total elapsed time from the time the vehicle entered the crater until it exited was 15 minutes. During some of the eleven unsuccessful attempts to exit the crater it was noted that the tracks were not turning even though the engine was laboring; this suggests a loss in power through the hydraulic transmission of the tank. Other times it was noted that the track on one side stopped moving, suggesting that a limited-slip differential that would apply power to both tracks might have enabled the tank to travel farther up the crater wall and possibly exit the crater. Several times the tank very nearly reached the rim and the driver shut off the power even though the vehicle was still moving forward, albeit at an extremely high rate of track slip. The reason for this was that when the tank had very nearly reached the rim, the driver could no longer see the ground; he had no reference point, and at high track slip he was unaware that the vehicle was still moving forward. This condition did not obtain in the other two craters because the tank was unable to climb high enough on the crater wall for the driver to lose sight of the ground.

3.2.2 Crater IIA-2. The tank entered the crater without difficulty, but could climb only about two-thirds the way up the crater wall when attempting to exit. The driver made repeated attempts, both by following the same path and selecting new paths. There was very little difference in the progress the vehicle could make up the crater wall, and such difference as existed was apparently more dependent upon the speed the tank reached before starting up the slope than upon whether or not the tank was in the old path or a new one. After numerous attempts over a 20-minute period, it was concluded that the tank could not climb out of the crater unaided. The D-9 tractor was used to assist the tank in climbing out of the crater.

When the tank had been recovered, the effectiveness of the lip and continuous ejecta in hampering mobility was tested by having the tank attempt to circle the crater at the outer edge of the inner lip. There was no loss in speed or driver control as compared with normal operation in the adjacent area unaffected by the blast. Indeed, the driver actually drove faster while making the circuit than he drove while traveling from one crater to another, probably because the surface was softer in the disturbed area, leading to a smoother ride.

3.2.3 Crater IIA-3. The tank had no difficulty entering the crater, but could climb only about one-half the way up the wall when attempting to exit. The D-9 tractor was used to determine the amount of construction effort required to make the crater passable for the tank. To simulate a tactical condition, the tractor bulldozed an entrance through the lip (see Figure 3.9). This served several purposes. It provided a sure way for the tank to climb out of the crater in the event the tractor might have been unable to backblade an exit, and the material pushed down into the bottom of the crater gave the tractor a higher point of attack on the opposite slope. Twenty-seven minutes were required to construct the entrance; 14 minutes were used to backblade an exit on the opposite slope (Figure 3.10). Approximately 250 cubic yards of soil were moved. Then the tank was able to exit the crater after 12 attempts (9 minutes). An elevation profile showing the results of the construction effort graphically is given in Figure 3.11. It was considered that this crater would require 1 bulldozer-hour of construction effort for it to be made passable for virtually any off-road military vehicle.

3.2.4. Analysis. The successful exit of the tank (even though on the twelfth attempt) from crater IIA-1 and the failure of the tank to exit craters IIA-2 and IIA-3 when the crater walls of all three craters had the same maximum slope merits some discussion. As stated in section 3.1.2,the differences in crater IIA-1 and crater IIA-2 as indicated by the elevation profiles of the apparent crater appeared rather subtle. It does not appear likely that the superior

performance of the tank in crater IIA-1 could be accounted for by the small differences in configuration of craters IIA-1 and IIA-2. The soil strength, as expressed by cone index, may provide part of the key to the better performance of the tank in crater IIA-1. The average cone index for the 0- to 6-inch layer (see Table 3.2) of the crater wall in crater IIA-1 was 55; in crater IIA-2 it was 50; in crater IIA-3 it was 39. The difference in strength between crater IIA-1 and IIA-2 may not be sufficient to justify the difference in performance, but by re-examining the cone index profiles (Figure 3.8) it may be seen that at greater depths there was a significant difference in the cone index for the crater walls of crater IIA-1 and IIA-2. The M48A2 tank at 98,000 pounds is a very heavy vehicle and it is likely that the increased strength at the greater depths aided the performance of the vehicle in crater IIA-1.

Another clue to the superior performance of the tank in crater IIA-1 may be found by considering the ejecta depth (Section 3.1.3). The stress bulb* formed in the ejecta underneath the tracks would have been intercepted by the true crater at a significantly less depth in the crater wall of crater IIA-1 than on the walls of the other craters. This could have resulted in a higher transient soil strength beneath the tracks of the tank in crater IIA-1 than in the other two craters.

Summing up, it is not possible to point out a single factor alone as the reason that the tank was able to exit crater IIA-1. Nor is it possible to state whether or not the tank could have exited crater IIA-1 on an earlier attempt had the driver not stopped while the tank was still moving forward, or had full power been delivered to the tracks at all times, or had the driver selected the eventual

* A full discussion of stresses induced in soil is beyond the scope of this report. This subject has been widely investigated[4,5,6] but generally in homogeneous materials. Few experimenters have considered the effect resulting when the stress bulb formed in a loose or soft material is foreshortened by a plane of rigid material. Some interesting photographs of this specific condition are shown in Reference 7.

path on the first instead of the twelfth attempt. It is unfortunate that the length of the test period did not permit a rerun of any of the tests with other drivers, because the possibility of driver influence appears to be indicated but is inconclusive. It has been established as a general rule from previous vehicle tests in craters that the driver will be apprehensive as the vehicle crosses the rim and drops down on the crater wall (a slope always appears steeper when looking down than when looking up). The driver will also be apprehensive when the tracks of the vehicle begin spinning in an attempt to climb a steep slope (the possibility that the tracks will dig out enough material that the vehicle will flip over backwards is remote, but the fear is very real). The tests reported herein tended to confirm this general rule. These dangers, whether real or imagined, preclude the possibility of having the vehicle approach the crater at full speed and thus obtain maximum momentum. As was apparent during the tests, some momentum is required for the M48A2 to negotiate a 68 percent slope; the vehicle is generally considered to have a maximum gradeability of 60 percent.[8]

Table 3.1

Summary of Physical Measurements of DIAMOND ORE Phase IIA Craters

	IIA - 1	IIA - 2	IIA - 3
CRATER WALL			
Average Diameter, feet (1)	162	160	144
Depth, feet (2)	25	23	30
Area, ft^2 (3)	20,600	20,100	16,300
Slope, percent (4)	68	68	68
LIP			
Crest Height, feet (5)	12	14	8
Inner Lip Width, feet (6)	47	51	46
Outer Lip Width, feet (7)	92	89	182
Inner Lip Area, ft^2	30,900	34,100	27,500
Outer Lip Area, ft^2	100,600	97,900	255,000
Inner Lip Slope, percent	26-34	20-38	10-34
Outer Lip Slope, percent	1-4	1-4	1-5

(1) From rim to rim

(2) Below original ground surface

(3) Area of plane tangent to rim

(4) Slope of crater wall

(5) Above original ground surface

(6) From lip rim to toe of inner lip slope

(7) From toe of inner lip slope to edge of continuous ejecta

Table 3.2

Summary of Cone Index Measurements

Terrain Unit	Surface	Average Cone Index 3-in.	6-in.	9-in.	12-in.	15-in.	18-in.	0-to 6-in. Average
Crater IIA-1								
Original Surface	54	320+	NS	NS	NS	NS	NS	320+
Outer Lip	31	83	162	320+	NS	NS	NS	92
Inner Lip	29	57	100	147	320+	NS	NS	62
Crater Wall	24	60	82	104	152	214	320+	55
Crater IIA-2								
Original Surface	56	320+	NS	NS	NS	NS	NS	320+
Outer Lip	35	116	128	320+	NS	NS	NS	93
Inner Lip	23	62	118	182	320+	NS	NS	68
Crater Wall	17	59	75	109	138	122	158	50
Crater IIA-3								
Original Surface	54	320+	NS	NS	NS	NS	NS	320+
Outer Lip	31	103	148	320+	NS	NS	NS	94
Inner Lip	30	61	65	132	320+	NS	NS	52
Crater Wall	10	45	61	84	85	86	102	39

NS - Not sampled; beyond range of instrument

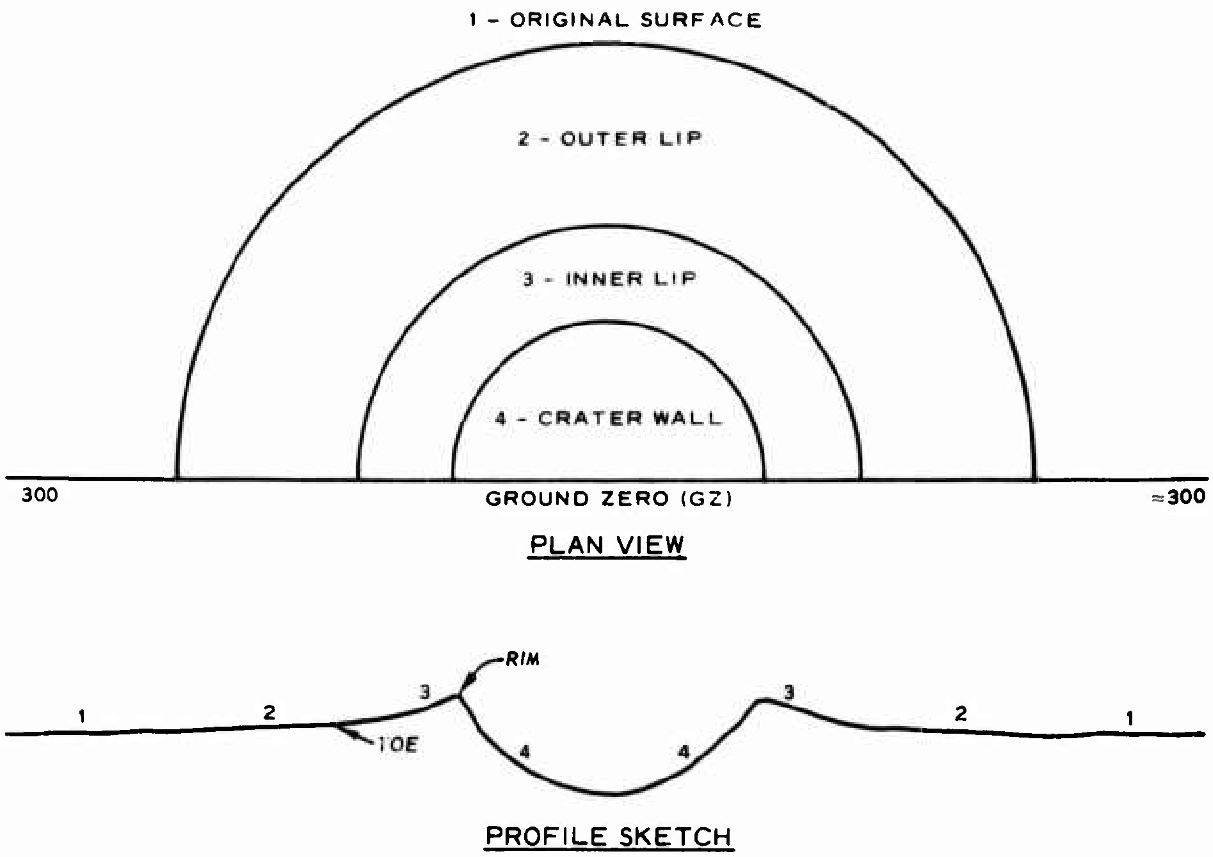


Figure 3.1 Schematic of terrain units in DIAMOND ORE Phase IIA craters.

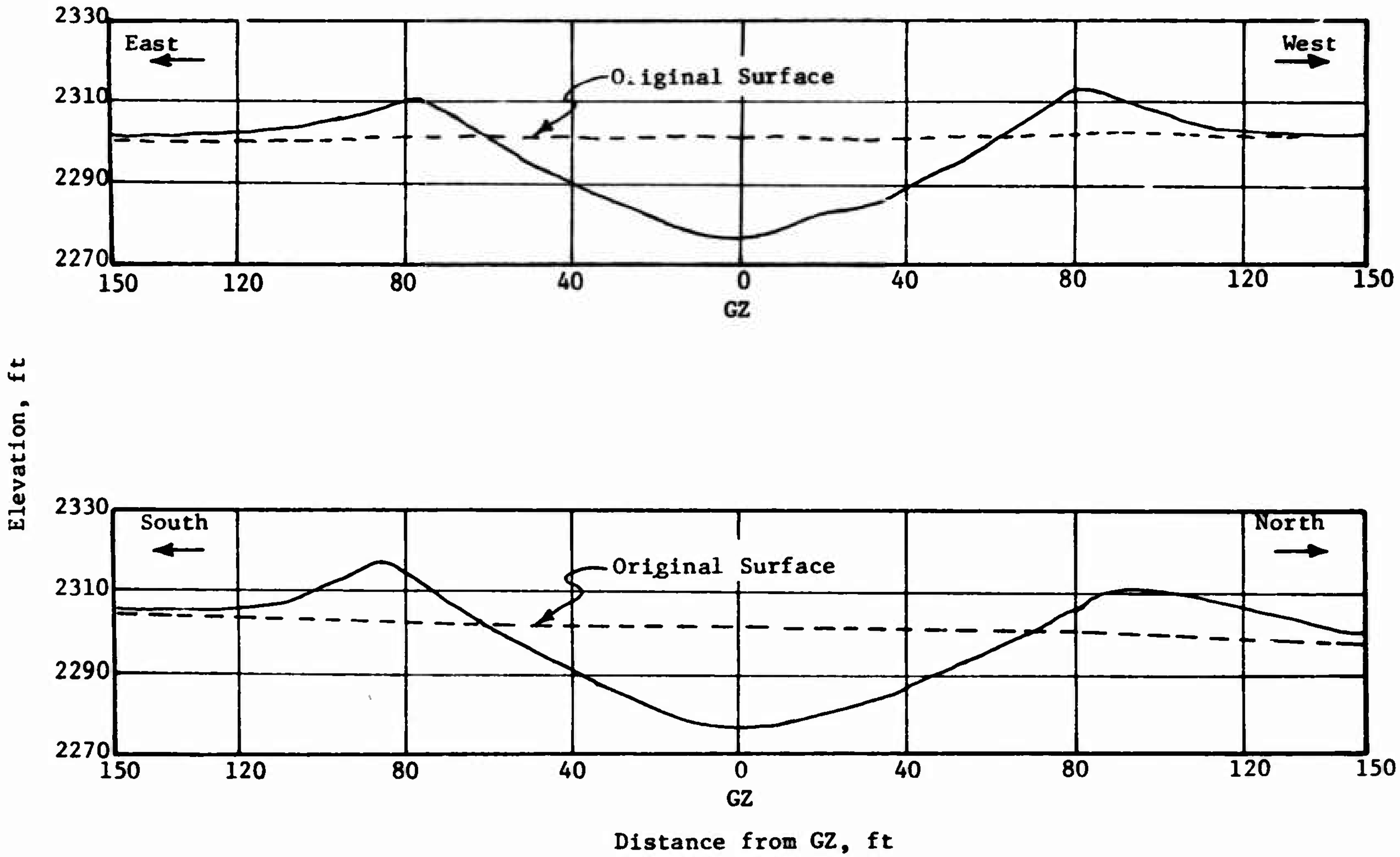


Figure 3.2 Profiles of crater IIA-1.

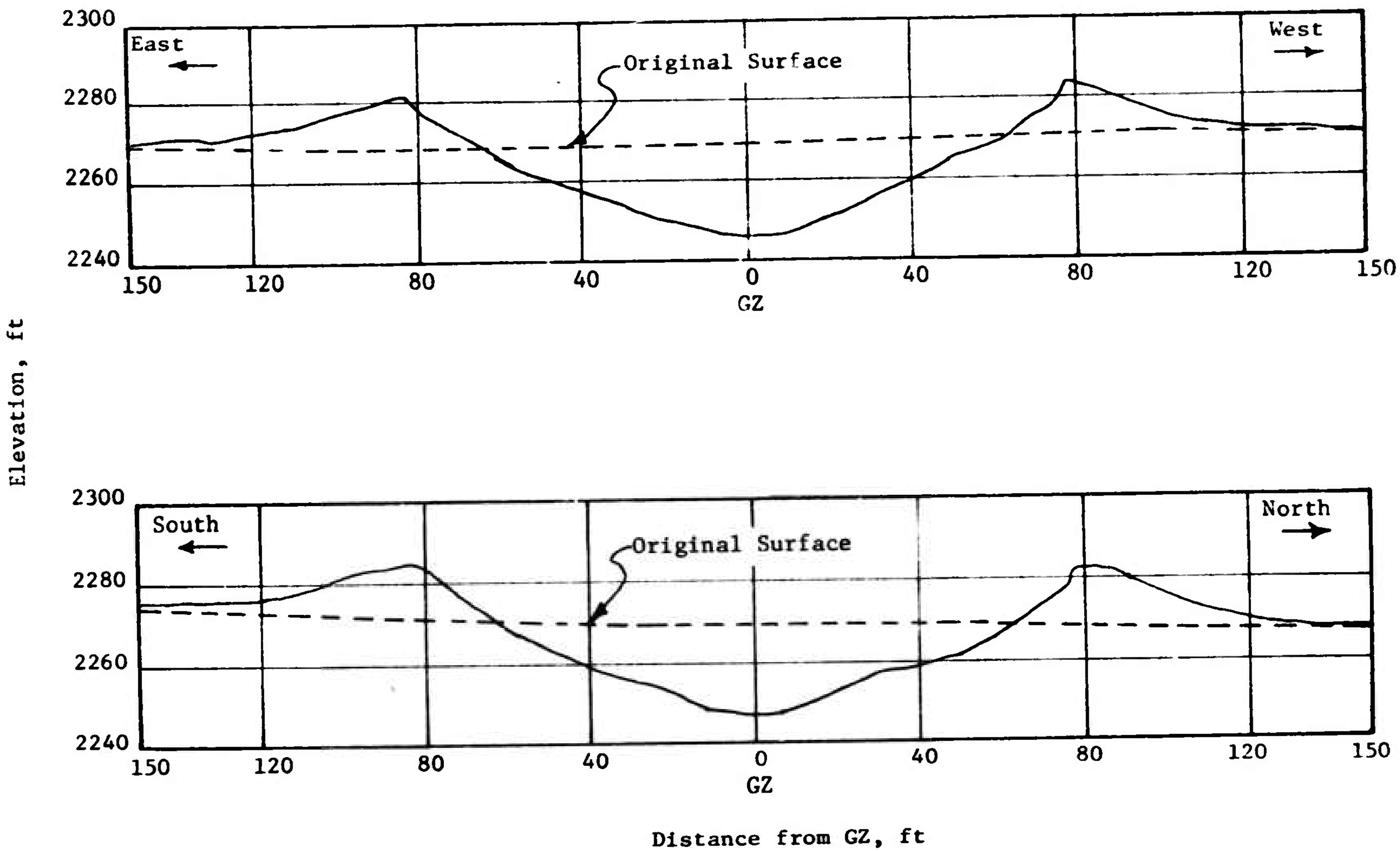


Figure 3.3 Profiles of crater IIA-2.

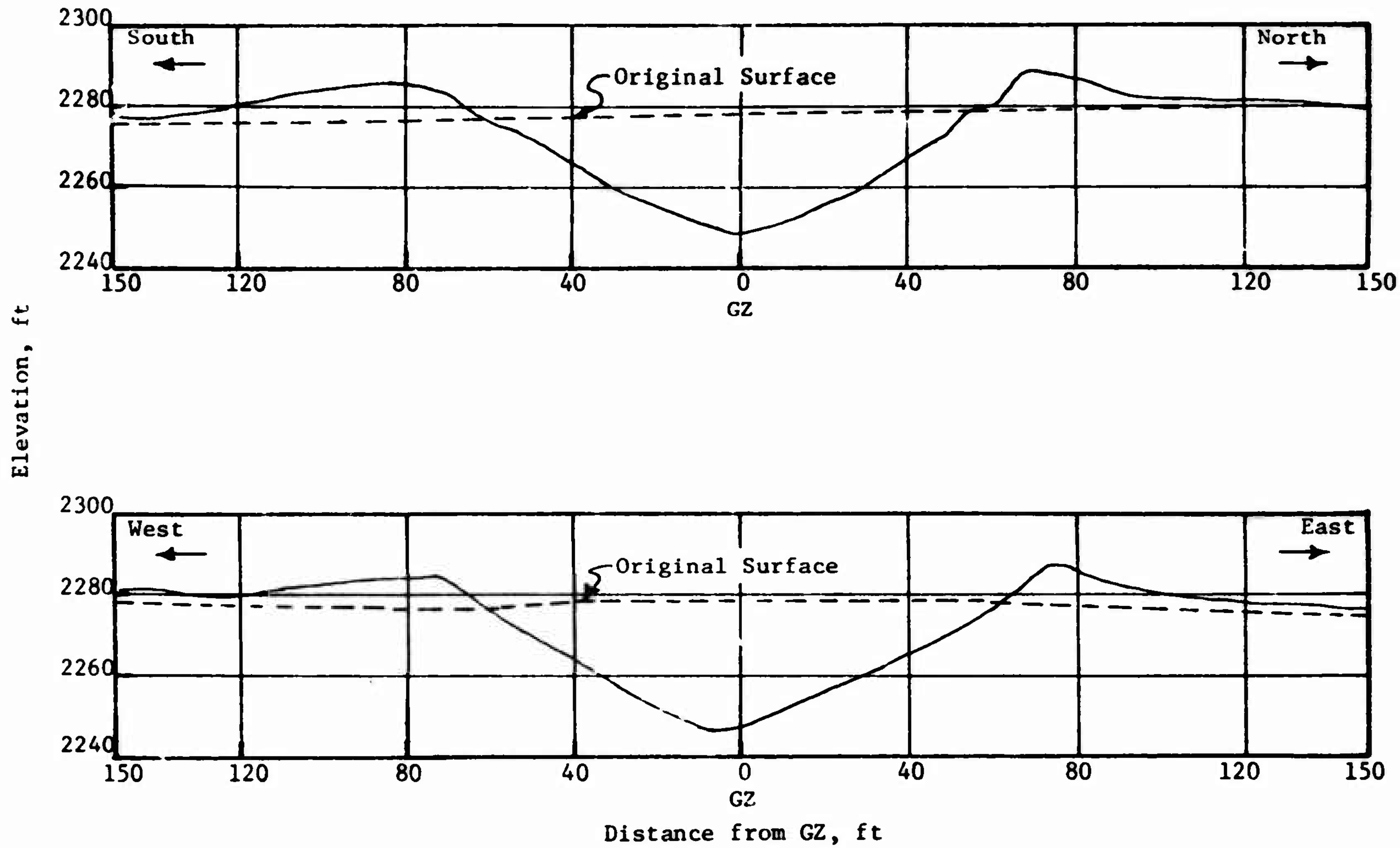


Figure 3.4 Profiles of crater IIA-3.

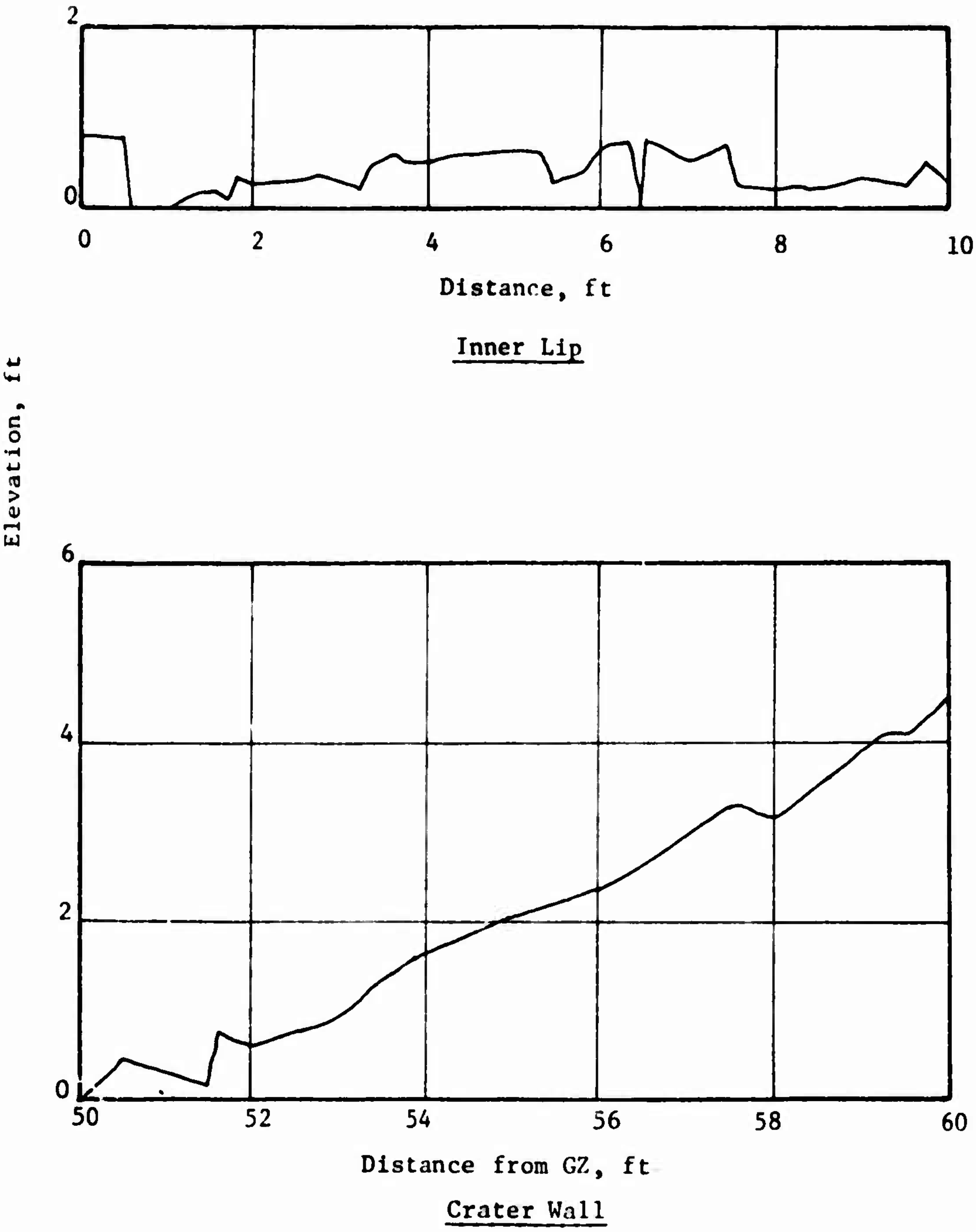


Figure 3.5 Microprofiles of crater IIA-1.

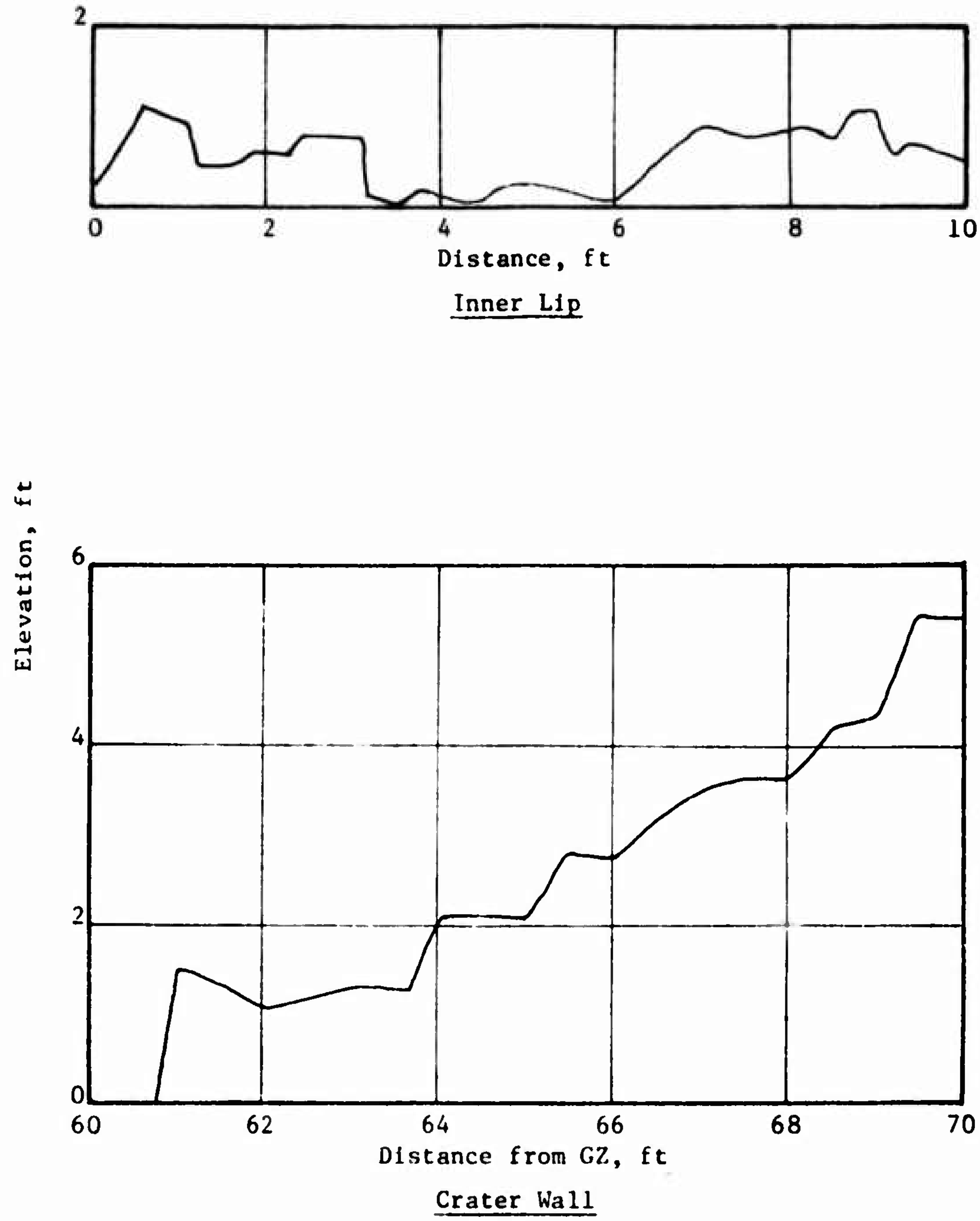


Figure 3.6 Microprofiles of crater IIA-2.

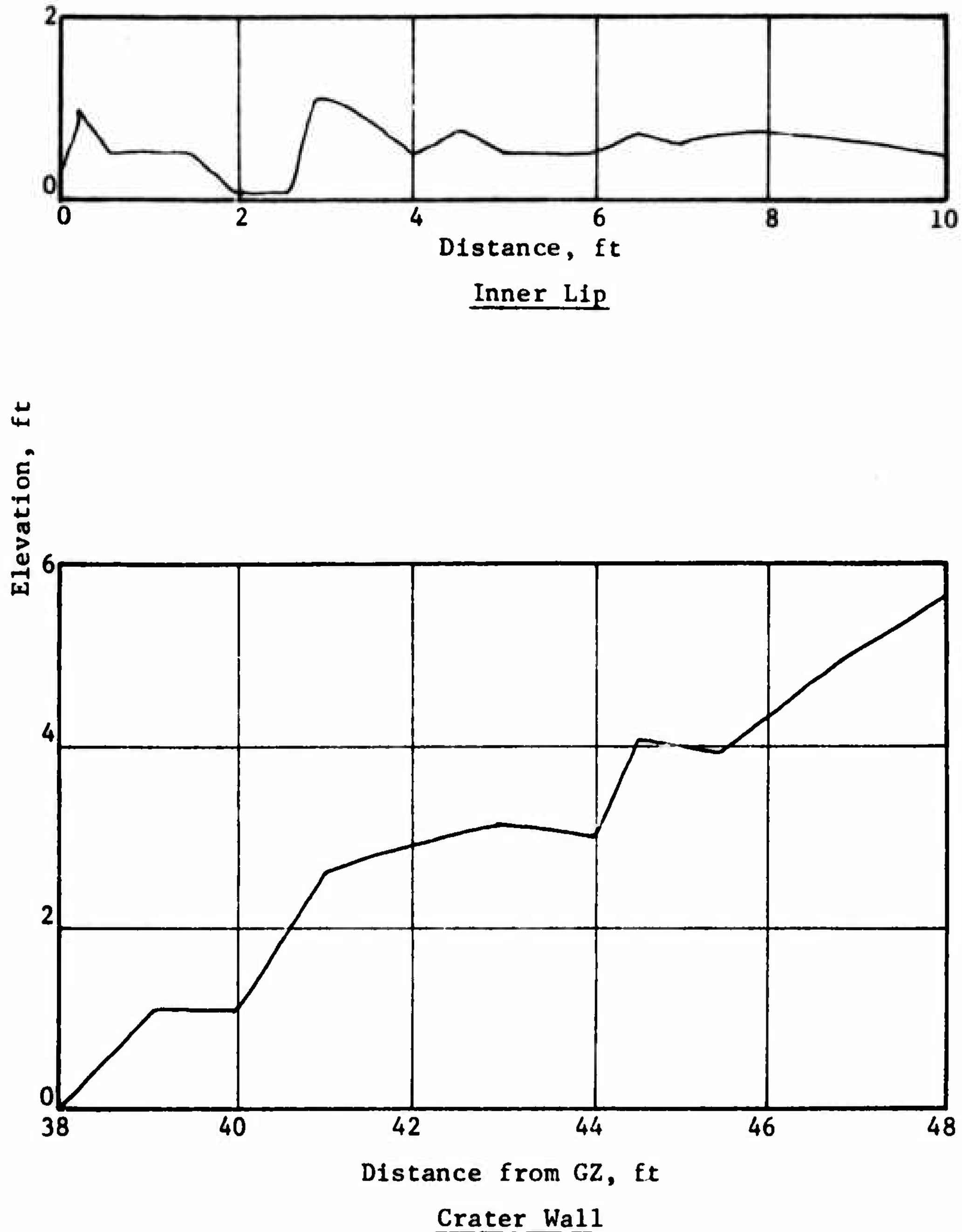
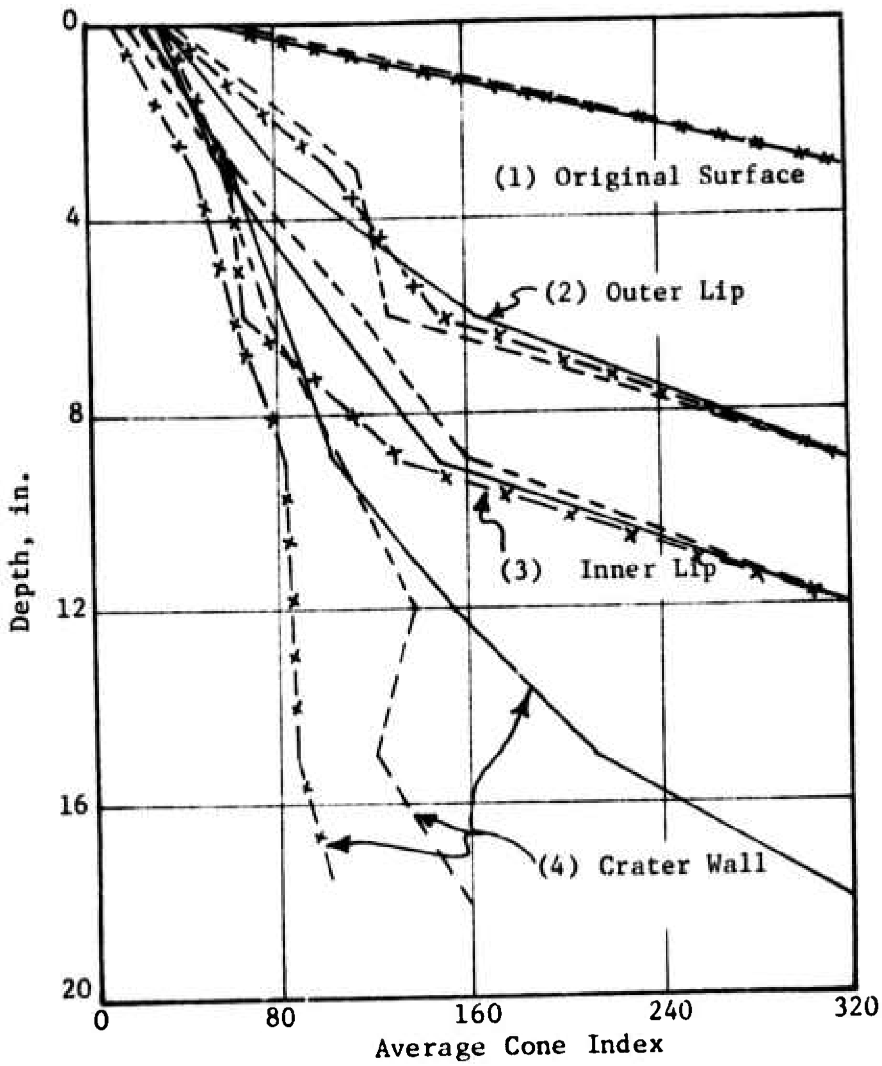


Figure 3.7 Microprofiles of crater IIA-3.



Legend

—— Crater IIA-1

- - - Crater IIA-2

-x-x- Crater IIA-3

Figure 3.8 Cone index profiles.

Figure 3.9 Entrance to crater IIA-3 as constructed by D9 tractor.

Figure 3.10 Exit from crater IIA-3 as constructed by D9 tractor.

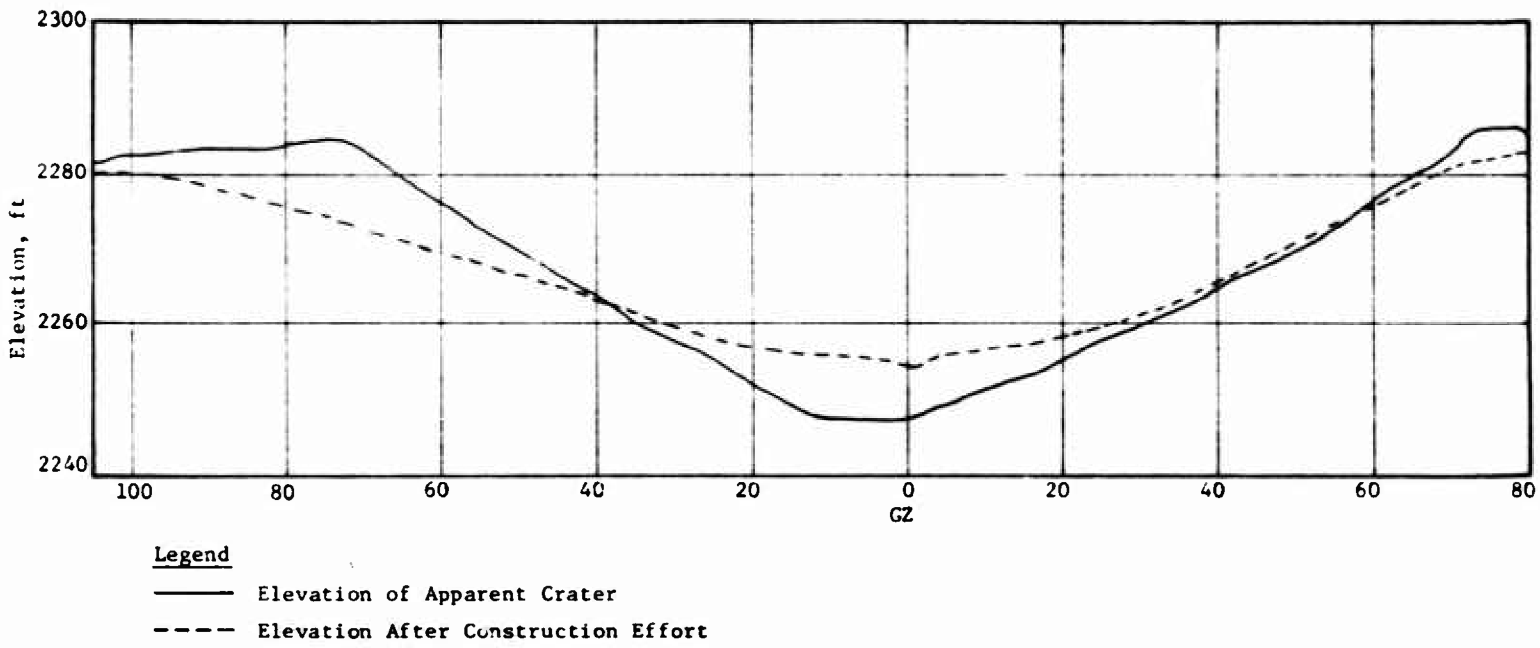


Figure 3.11 Profile of crater IIA-3 showing construction effort.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The following conclusions are based on the data reported and the references cited herein:

The tests clearly demonstrated the importance of stemming when placing a buried charge to create a barrier for the M48A2 tank in this soil type. The unstemmed charge that formed crater IIA-1 was placed at optimum DOB and created a marginal condition of "go-no go" for the M48A2. The stemmed charge that formed crater IIA-3 was placed at slightly less than half the optimum DOB and yet created a definite barrier to the vehicle.

When consideration is given to the 9- to 18-inch cone index on the crater wall in crater IIA-3 as compared with that in crater IIA-2 and to the further travel of the M48A2 upslope in crater IIA-2 (even though neither crater was passable for this vehicle), there exists some doubt that placing a charge at the optimum DOB yields the most severe barrier for the M48A2 tank in this soil type.

The engineering effort (bulldozer) required to make crater IIA-3 passable for the M48A2 was 1 bulldozer-hour.

The lip and continuous ejecta in clay shale did not present a mobility problem for the M48A2 tank.

4.2 RECOMMENDATIONS

It is recommended that investigations be conducted in a range of consolidated and unconsolidated layered materials to increase the catalog of crater terrain information for ground mobility purposes. These investigations should also include vehicle tests to collect data for refining techniques for predicting vehicle performance in crater ejecta. These techniques should include a simple and rapid solution to be incorporated into field manuals for predicting performance in cratered terrain that will evaluate all terrain factors of

significance to mobility.

It is further recommended that in all future test programs, the amount of construction effort required to remove ejecta and to bypass, bridge, or fill craters to make them passable for ground vehicles be determined.

It is also recommended that in future test programs, the effects of the crater and its associated ejecta on vehicle performance should be determined in terms of speed rather than on a go-no go basis so that the degree of difficulty encountered in each terrain type can be determined.

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